THE SPEED OF ADJUSTMENT OF THE EYE FOR CLEAR SEEING AT DIFFERENT DISTANCES [1]

A Study of Ocular Functions with Special Reference to Aviation

By C. E. Ferree and Gertrude Rand, Bryn Mawr College

By speed of adjustment is meant here speed in the action both of the extrinsic and intrinsic muscles in adjusting for clear seeing at different distances. The amount of lag in this function is found to vary a great deal from individual to individual. In the results to be presented the minimum time required to change from the adjustment for clear seeing at or near the near-point to that for clear seeing at 6 meters, and the converse, has been measured in several cases. So far the investigation has been conducted primarily as a study of the method with special reference to its applicability as a test of fitness for vocations for which speed and accuracy of adjustment are a prerequisite. In this particular especially, the writers believe that the aviator must excel. The rapid development of the science and art of aviation brought about by the present war emphasizes the need for tests which will facilitate the selection of the supernormal eye. It is scarcely to be expected that the conventional clinic tests, designed more particularly for the separation of the subnormal from the normal eye, are fully adequate for this purpose.

It will be obvious without discussion perhaps that in estimating the fitness of an instrument, apparatus, or human organ for a particular task or for the range of work which it may be called upon to perform, other aspects besides maximum power or capacity of response should be taken into account. Some of these are lag, steadiness or stability of response, power to sustain response, rate of fatigue or decay of response, rate of recovery, etc. All of these functional aspects are present in particular in case of the eye; and their variation from time to time in a given eye and from eye to eye can be measured with a degree of precision that is adequate at least for many comparative purposes. As

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has already been indicated, we have been concerned in the present work with only one of these aspects, namely, the *lag* in the eye's reactions to its stimulus. In the study of this phenomenon at different times in our laboratory, three subdivisions have been made: the lag in the response of the retina to colored and colorless light and its change with change in the intensity of light, the lag in the adjustment of the eye for clear seeing at different distances, and the lag in the development of the perception of depth or distance. The relation of all of these to the functional efficiency of the eye will be considered very briefly in passing.

Because of its small order of magnitude the first of these types of lag is of comparatively little importance in the most of the uses to which the eye is put. In all acts of seeing, for example, in which a change of adjustment is required, the lag in the retina's action is insignificant in amount as compared with the lag in the muscular action. It becomes of importance only in such uses of the eye as permit of a very short exposure to its stimulus, usually with the muscular adjustment already made, or in cases in which it is important to have the maximum response of which the eye is capable. Examples of the former may be found in various uses of the eye in the technical work of the laboratory; and of the latter in signaling with colored and colorless lights. In order to show something of the order of magnitude of the lag in the retina's response and its variation with the wave-length and intensity of light used, we have constructed curves in which the sensation as it rises to its maximum value is plotted in just noticeably different steps against time of exposure. These results were obtained in our laboratory three years ago in a comparative study of methods of determining lag.[2] Four of the most promising of the older methods and three new ones were used in making the determinations; and the results of the several methods were checked against each other. The comparative study was made throughout on the same observers. The dominant motive in making this study was to find or devise a method which would have sureness of principle and precision and at the same time the feasibility that is needed for practical applications. One of the new methods was found to answer surprisingly well to these requirements, considering the nature and difficulty of the problem. The lights employed were narrow bands in the red 686 $\mu\mu$, yellow 588 $\mu\mu$, green 511 $\mu\mu$ and blue 463$\mu\mu$ and white light. The colored lights were taken from the prismatic spectrum of a Nernst filament and the

[2] We are indebted for these results to M. A. Bills, a former graduate student.

white light was synthesized from this spectrum. The lights were all made photometrically equal and in addition, for the sake of more absolute specification, their physical intensities were measured by means of a thermopile.

The results obtained showed that observers differ in all of the following regards: amount of lag for a given stimulus, the amount of difference in the lag for the different wave-lengths and for white light, and the effect on these differences of changing the intensity of light. In case of the observer whose results are given in Fig. I, three intensities of light were used, 0.057, 0.151 and 1.21 meter-candles. It will be noted that for the lowest of these intensities, the rate of rise to the maximum was in the following order: yellow, red, blue, green and white, the time of the maximum ranging between 0.1 and 0.22 sec. For the highest intensity the rates of rise were in the order: Green, yellow, white and red, the time required to reach the maximum ranging between 0.085 and 0.14 sec. Blue was omitted from this series because it could not be obtained at the required photometric value. At the intermediate intensity, a transition condition is shown which can best be gotten from the charts. That is, in passing over a certain range low in the intensity scale to points higher in the scale, there is a radical change in the order of rate of rise tending towards a complete reversal at high intensities; while at intermediate points in the scale, the lag is shown to be in a stage of transition between what is present at low and high intensities. An increase is found also in general to lessen the lag very considerably or to increase the rate of rise. These details, however, are much more important in certain phases of the use of the eye in laboratory technique, for example, than they are in immediate relation to the work of the present paper. Our purpose in introducing them here is, as we have already indicated, merely to give some general idea of this feature in the eye's slowness in responding to its task, and in particular to show that as compared with its inertia of adjusting clearly to receive its impression, the inertia in its sensory reaction is relatively unimportant for most of the work which it is called upon to do.

So far our investigation of the lag in the perception of depth has been made in stereoscopic vision, and for an entirely different purpose than the grading of individual capacities. The results show, however, that depth comes into the percept later than height and breadth and color and brightness; and that the amount of lag varies for different observers. Whether this type of lag could be made a feasible basis for the grading of individuals for vocational purposes, we are not prepared

at this time to say. Speed and accuracy in judging distance are doubtless important items in the qualification of an aviator, for example; and it may be possible to work out feasible tests for certain fundamental aspects of the ocular foundation of this ability. Indeed the lag in the adjustment of the eye for clear seeing at different distances should sustain a somewhat fundamental relation to speed of judging distance, since both the adjustment of the eye and the clear seeing of objects are in general the important ocular functions involved in the judgment of distance. Unfortunately for our purpose, however, the judgment itself is not an ocular function. The eye provides only the criteria, and a very complex set of criteria at that, from which the individual learns by experience to form his judgments of distance. The testing of these extra-ocular capacities, the ability to estimate and to learn to estimate distances, more particularly under an entirely new set of conditions for which definite standards or patterns are wanting, is perhaps just as important as the testing of the ocular capacity itself. The testing of the ocular capacity as registered in certain simple space judgments, with or without the element of time or speed of performance, is capable of definite treatment. All that can be said of the remainder of the problem is that it is open to investigation.

On quite a different methodical plane, however, is the determination of the lag in the adjustment of the eye for clear seeing at different distances. The making of these determinations by the method we have used involves no extra-ocular capacities of a higher order than are required in the acuity tests for illiterates. Moreover, a direct objective check is applied to the subjective judgment. That is, the letter E built to scale and turned in different directions is used as a test-object for the different distances; and the observer is required only to indicate the direction in which the letter points in any given case. Such testing of human functions, even without the objective check, is, so far as method and principles of testing are concerned, just as definite as the testing of those physical instruments, whose responses must be read by the eye from a moving pointer and scale or their equivalent.

Our purpose in making these tests has been, as we have already indicated, primarily to ascertain whether eyes rated by the clinic tests as normal or approximately so cannot be more finely graded as to their working efficiency or fitness for special purposes, when other important functions than those considered in the clinic tests are taken into account. For this purpose we have aimed, therefore, to test for the greater part only eyes that have been passed in the clinic as normal, or as

having defects so insignificant as not to need correction. Ninety-four per cent of the eyes of this group were able to read quite readily at 6 meters under 5.2 foot-candles of light the test-type designed to be read at 4 meters; and the remaining 6 per cent, the type designed to be read at 5 meters. In addition a few were tested whose eyes were corrected by glasses. This was done for the purpose of getting results comparative of the performance of eyes corrected to standard according to the norms of the clinic and the uncorrected normal eye. All but one of the uncorrected group were between 18 and 28 years of age and only one of the corrected group was over 28. Three of the observers had worked pretty steadily for a year or more with high power microscopes, four were trained in the observations of physiological optics, and the remainder were selected at random from the college community. The best results were obtained from one of the three who had been trained in the use of a high power microscope; but her results were closely rivaled by those of a college sophomore whose eyes and observational powers had received no special training. However, the results of the three whose eyes had received special training in the use of the high power microscope averaged rather strikingly high. To what extent speed of adjustment can be trained is yet to be determined.

Fortunately for the feasibility of the test, the immediate practice effect is low, or more properly speaking, it is rather high in the initial observations but soon ceases to be troublesome. Also the precision for any given set of determinations is high. As might be expected, though, there is a diurnal variation in the results corresponding to the diurnal changes in the function tested. The maximum range of these variations, however, is small as compared with the range of variation between individuals. It is not great enough, so far as we have thus far been able to determine, seriously to affect the grading of eyes with sufficient precision for practical purposes on the basis of the tests taken at any one time chosen at random. The fact that there is a diurnal variation suggests, however, that if the test be used as a check on fitness for aviation, it might be of advantage to determine each individual's norm and require a short test before each flight, or as often as may be needed to keep track of the variations and to safeguard against the more serious depressions that may occur.[3]

[3] If a check is wanted on the diurnal variations in other motor coordinations as well as those of the eye, a reaction experiment involving choice may readily be combined with the ocular experiment. Two

The working distance for the far object was chosen as 6 meters and for the near object as 18 cm. The far object at this distance subtended a visual angle of 7 min.; the near object, 14.8 min. In choosing both the working distance and the visual angle for the near objects care was taken not to approach too closely to the limiting values. This was needed to safeguard the results against individual differences in the near point and in acuity. That is, it was found that unless these limiting values were too closely approximated, small variations either in the visual angle or the working distance produced little difference in the results.

Since our problem was in part to devise and try out apparatus, the determinations have been made with two types of apparatus, one of which is slightly simpler in construction and use than the other. By means of the more complicated apparatus, however, a more complete analysis of the problem is possible. That is, by means of the simpler apparatus it is possible to make the following determinations: the lag of perception with the eye in approximate adjustment for the near object, the time required to change from this adjustment to that required for far seeing, and the time required for the double excursion, *i. e.,* from near to far and back again to near; while by means of the other apparatus we were in addition able to break up the double excursion into its two halves, the time required to pass from near to far, and back again to near. By means of the second apparatus, moreover, all of the determinations may be made in a single swing of the compound pendulum governing the time of exposure.

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forms of this reaction experiment are suggested. (1) A four-finger reaction key may be used, each of the keys to indicate one of the four possible positions of the letters—up, down, right and left. That is, the observer just as soon as each letter,—near, far, and near—is discriminated indicates the direction in which it points by pressing the proper key. (2) A wider range of coordinative ability could be tested by having two keys operated respectively by the right and left hand, and contacts by the right and left foot. By soldering contacts on each edge of the exposure discs in circuit with an electro-magnetic marker and by having the reaction keys and foot contacts also in circuit with electro-magnetic markers, the length of exposure for each test object and the reaction times could all be recorded simultaneously on a kymograph, together with a time line traced by an electric tuning fork. With these records as a check on the quickness of the motor functions of eye, arms and legs and the mental functions involved in choosing, it would seem scarcely possible that the aviator could grow stale or suffer even temporary depressions of any consequence without the knowledge of the laboratory corps. Also from the accumulated records a comparative rating of the stability of the men could be made. It may be, of course, that the eye records alone will serve as a reliable index of the variations in the observer's general condition, but that correlation has not as yet been investigated.

There is another advantage of the second apparatus which came out quite plainly whenever a comparison of results was possible on the same observer. That is, in its use a provision was made to cut off each test object just as soon as it was discriminated. The eye was not allowed to linger on the far object as was its tendency when the double excursion was not broken up into its two halves. The value of the double excursion as determined directly by the first apparatus was, for example, appreciably longer than when it was determined by adding together the values of the two halves as determined by the second apparatus. This tendency of the eye to linger where it can thus not only makes a difference in the absolute value of the results, but there is a danger that it may affect also the comparative values. That is, the latitude offered not only gives a chance for a variable performance or a variable error from time to time with the same observer, but it leaves the results open to the influence of this factor in case of different observers.

Obviously the test may be used in two ways. (1) Records may be made of the maximum performance of each individual. This would be the analogue of making acuity tests in terms of the minimum visual angle each observer is able to discriminate. This procedure is the longer of the two but results in a much finer grading of performance. (2) Two, three, four, or any suitable number of levels of performance may be chosen and the apparatus set at once to give these levels. This method of testing would roughly place individuals into ranks or groups and is the analogue of the Snellen method of grading acuity. It is a much quicker procedure but the grading made is correspondingly rough. By this method the ranking or testing of a given individual by a practiced person should occupy but a few minutes. The results given in this paper were obtained entirely by the former method. It is obvious that the latter method could not be used until sufficient work had been done by the former to establish the required norms for the vocation or purpose in question. Results obtained with the two types of apparatus are shown in Tables I[4] and II.

Since these tables are somewhat detailed, it may be of advantage to give in advance a few points by way of a very general statement of results. The time required for the 18 normal observers to pass from near to far varied between 0.50—1.16 sec., a range of 132 per cent; from far to near, between 0.39—0.82 sec., a range of 110.3 per cent; and from near to far

[4] For the greater part of the results given in Table I we are indebted to M. Almack, a graduate student in our laboratory.

and back to near, from 0.96—1.76 sec., a range of 83.3 per cent. Of these observers, 15 or 83⅓ per cent, required longer to change from near to far than from far to near.[5] If a rough classification by rank were wanted, they might readily be divided into three or more groups with abundance of difference between groups for a graded setting of the apparatus. If, for example, three groups are chosen: fast, medium and slow—fast ranging between 0.95—1.25 sec., medium between 1.25—1.55 sec., and slow between 1.55—1.85 sec., 28 per cent would fall in the first class, 55 per cent in the second class, and 17 per cent in the third class. The observers who wore glasses all grouped together with the slowest of the normal class. The time from near to far for these observers ranged between 0. 89—1.17 sec.; from far to near, between 0.41—0.68 sec.; and the time for the double excursion, between 1.48—1.58 sec. The fastest of this group was 54.2 per cent slower for the round trip than the quickest of the normal group. Under the age of 30, there seems to be no correlation in either group with the age of the observer.[6]

There is a possible bearing of the principles of the test on the work of the clinic which perhaps should not be ignored. That is, in the conventional acuity test accuracy alone is taken into account. No provision is made in the form of the test to include speed of performance. When speed is added to accuracy as a requirement, a degree of sensitivity is given to the test which enables a much finer grading of the resolving power of the eye. For example, two eyes which discriminate detail within the same visual angle can not be said to have the same acuity unless the task can be performed in the same or very nearly the same length of time; yet both might be given the same rating by the conventional test of acuity so far as any safeguarding provision to the contrary is concerned. Indeed when speed is made a feature of the test, differences are readily picked up which would be passed over entirely by the clinic test. Such a refinement of the test need not be especially cumbersome when properly applied to the needs of

[5] The longer time to pass from near to far may, to some extent of course, have been due to the smaller visual angle subtended by the far object. That is, the time required to discriminate the far object may have been increased by its relatively smaller angular value.

[6] So far but few observers have been tested above 30 years of age. The few that have been tested have averaged among the slowest of the normal group. We hope later to make a systematic study of the effect of age on speed of adjustment. In the present study our special purpose has been merely to find out whether individual differences of considerable magnitude are present well below the limit at which the influence of age might reasonably be expected to become effective.

the practitioner, and might, it would be reasonable to suppose, be utilized to advantage as a means of making a more precise diagnosis and in checking up and deciding between corrections, at least in certain difficult and troublesome cases.

From the beginning of our work with short exposures, results were obtained which may have some interest in relation to testing for astigmatism. For example, it was found that in certain cases there was a more favorable meridian for the quick discrimination of the test object. That is, when turned into this meridian a shorter time of exposure was needed to give the judgment required, and small deviations on either side increased the time needed to make the discrimination. In case of the eyes of one of the writers (Ferree), for example, a difference in result amounting to 40 per cent was found for this meridian and the meridian at right angles to it. A deviation of 5 degrees either way from this most favorable meridian gave a difference in result amounting to 16 per cent. The astigmatism was so slight that it could not be detected on the astigmatic chart. It was located by means of the ophthalmometer. A +.12 cylinder served to make the time record equal for the two meridians and to eliminate the astigmatic showing by the ophthalmometer. On further study of several cases the test was shown to possess a pronounced sensitivity to astigmatism even without any additional or special modification better to meet the requirements of that particular application.[7] Some of the results of this study are shown in Table III.

The requirements of the apparatus needed to make the foregoing determinations are comparatively simple. Some means must be provided for giving the exposures to the near and far test objects which will immediately succeed each other in the required order and which can be varied by very small amounts and be repeated with precision. The first of the above requirements can best be met by making the successive exposures all a part of the same system of motion. The simplest way in which all of the requirements mentioned can be satisfied is perhaps to have the exposures made by means of a set of lightweight discs of variable open and closed sectors turned by means of a bar fastened at its center to the axle to which the

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[7] Before the lag records are made it is recommended, of course, that astigmatisms be corrected. However, even if they are not corrected, low astigmatisms will give little trouble unless the defect is in the same meridian in both eyes. There will then be more and less favorable meridians for the quick discrimination of the test object. The difficulty can be overcome fairly well, however, and the record be made without serious injustice to the ranking of the observer by avoiding turning the test object into the most and least favorable meridians.

discs are attached and provided with adjustable weights on both arms. Such a system operates as a compound pendulum and has all of the characteristics and constancy of motion of a compound pendulum. The length of exposure can be varied either by changing the width of the open sector or the position of the weights on the arms. By utilizing both of these variables to their fullest extent, changes can readily be made of the order of thousandths of a second or even less, and a total range of exposure can be given varying from these values up to several seconds. Most of our work was done, for example, by one adjustment of the position of the weights on the arms, giving a slow rate of turning. Constancy of rate of turning and therefore constancy of length of exposure with a given value of open sector and a given position of weights on the bar was secured by always releasing the bar at the same point in the arc through which it makes its swing. On the back of each set of discs is a protractor or graduated circle by means of which the values of the open sectors can be read to degrees or fractions of degrees. These values in degrees for any number of observers or observations, if the discs are made of sufficiently light material, can be converted into units of time by a single process of calibration which will be described later.

In Fig. II is shown the first or simpler apparatus. The exposure discs A, B, C and D are cut from hard sheet aluminum, No. 20 B & S gauge. Each of these discs are cut as shown at X in the figure, the inner portion, radius 6.5 cm., solid; the outer portion open to a value of 172°. The breadth of this outer zone for discs A and B is 14.5 cm.; and for discs C and D, 22.5 cm. The difference in the breadth of these two sets of discs has to be such that the smaller will just cover one of the near test objects, and the larger, the other, the two objects being placed far enough apart in the same vertical plane to permit of a clear view between them with either eye of the far object. All of these discs are attached to an axle to the end of which is fastened the bar, 2½ meters long, which carries the weights, M and N, which serve as the driving power of the apparatus. These weights are of equal mass, therefore the moment of turning of the system is governed, roughly speaking, by two factors; the combined distance of the two weights from the center of rotation, and the difference in the distance of the weights from that point, provided, as already stated, the swing is always begun at the same place in the arc through which the system turns. To give stability of support the axle turns in bearings at the ends of the two arms of a heavy Y-shaped support. A clutch, adjustable in

height, supports the bar before it is released for its swing and guarantees that it always starts from the same position. The discs A and C are pinned permanently to the axle in such a position that when the bar is held in the clutch, A just covers one of the test objects and C the other. The discs B and D are free to turn about the axle and when adjusted for a given value of exposure are clamped in position by means of a nut and washer. Immediately in front of these discs are the two octagonal cards at the center of each edge of which is printed one of the test letters. These E's are so turned that by rotating the card the letters can be presented all precisely at the same place, pointing up, down, right, left, and the four corresponding 45° positions in any order that may be chosen. The card itself is mounted at its center on a small metal disc at the end of a grooved pin 6.5 cm. long. This pin passes through a collar provided with a set screw which feature permits of a certain latitude of adjustment of the distance of the test card from the exposure discs. To provide for the rotation of the test card this collar turns in a sleeve supported by a grooved carrier. This carrier slides on a track, to permit of the needed latitude of adjustment of the test-object to right and left. The far test object is printed on a larger circular card which is mounted at its center on a small metal disc at the end of a pin which passes through a broad collar permitting of its free rotation. At the other end of this pin is a pulley so arranged that by means of two cords which thread through a guide ring 21 cm. below the center of the pulley, the card can be rotated to any position desired by the experimenter stationed at the exposure apparatus. The circumference of this card which turns immediately behind a pointer is graduated in degrees to indicate the meridian into which the test letter is turned. Between the observer and the exposure discs, as near to these discs as possible, is a cardboard screen with an aperture of such a height and breadth as to give a clear view of the near and far test object with either eye and to cut off the rest of the field of view and the moving discs.

The near test cards were illuminated by diffuse light reflected from the mat surface of the back of the cardboard screen between the observer and the exposure discs. The light was supplied by a tubular tungsten lamp enclosed in a cylindrical housing provided with a vertical aperture of a suitable breadth. This housing can be rotated about the lamp to give the proper angle of incidence of the light on the reflecting screen. The far test object was illuminated by a tungsten lamp mounted in an X-Ray deep bowl reflector so

directed as to give an even illumination of the test surface and to shield the eye from glare. All of the test objects were brought as nearly as possible to a brightness and color match at a brightness value of 0.007 candlepower per square inch. The value of the illumination at the test object was 5.2 foot-candles. The general illumination of the room was indirect with an average value of 2.89 foot-candles, vertical component; 1.11 foot-candles, horizontal component; and 2.64 foot-candles, 45° component.

The experimental procedure was as follows. The three test objects and the eyes of the observer were adjusted to the same vertical level, and the two near objects were separated far enough to give the observer a clear view of the far object with either eye. Discs A and B were adjusted so as just to permit of the discrimination of the near object immediately in front of them; and C and D, the discrimination of the far object in case the time to pass from near to far is wanted, and of both the far object and the remaining near object in case the time of the double excursion is desired. In making each determination three correct judgments out of a possible five were required. A preparatory adjustment of the observer's eye was secured by having him fixate a point on the discs in line with the near object first exposed and 3 mm. nearer to the eye. In order that the preparatory interval be as favorable as possible, the observer was required to give the signal for the release of the pendulum.

It should be noted in passing perhaps that the adjustment of the discs A and B is not made entirely or even primarily for determining the lag in perception with the eye in approximate adjustment for the near object, although that is an item that might be of value perhaps in our comparative study of the lag of the ocular functions of different individuals. It has been made chiefly in order that the determination of the time to pass from near to far and back again to near shall be made with greater precision. That is, it is obvious that if the observer is to begin his excursion from near to far with an exact adjustment for clear seeing at near, it must be required as a check that he start with a task which involves a report of clear seeing at near. The mere instruction to fixate a point, for example, will not guarantee the needed adjustment. Moreover, it is equally obvious that the adjustment must be precisely controlled if the results are to be safeguarded against the variable error that has already been discussed with reference to the exposure of the far object. That is, if it is not controlled, the eye may linger too long at near or begin too soon its change towards far, and the amount of deviation in either

regard may vary from time to time and from individual to individual.

In the second type of apparatus (Fig. III) our purpose, it will be remembered, was to make it possible to do all that could be accomplished with the first apparatus, and in addition to provide for the separate determination of the time required to pass from near to far, and back again to near in a single swing of the pendulum. In order to do this it was necessary to have behind the near test objects a second set of discs attached to the same axle, one of the sectors of which when properly adjusted cuts off the far object as soon as it is discriminated. That is, in this apparatus, the aperture of the two smaller sectors, A and B, of the nearer set of discs gives the time of perception of the near object on the observer's left; the aperture between B of this set and F of the farther set gives the time needed to pass from near to far; and the aperture between this disc and the disc D of the nearer set the time required to pass from far back again to near. The other discs, E of the far set and C of the near set, are pinned permanently to the axle and are rigidly connected, with the edge of each at exactly the same level. Both sets of discs are provided with graduated circles. At the edge of each of the moveable sectors are pointers for reading the values of the open sectors. As the apparatus now stands, the two sets of discs are both between the Y-shaped support and the observer and are only 10 cm. apart. Since the graduated circles are on the back of each set of discs, this makes the reading of the circle on the near set somewhat inconvenient. In a new apparatus now in construction, the near set will be attached between the observer and the support in which the axle turns, and the far set beyond this support. This provision will give ample space between the two sets of discs for the convenient reading of the scale on the near discs.[8]

[8] Also in the newer form of apparatus the near test cards are illuminated by a tubular tungsten lamp installed in the horizontal in a plane midway between the screen and the near test objects, so that the center of its filament is about 12 cm. above the two test objects and equidistant from them. The test objects thus receive their light in part directly from the lamp and in part by reflection from the screen. In this way it is possible to make the intensity of light received by the two objects more nearly the same than is the case with the illuminating device shown in Figs. III and IV. On the platform between the two sets of discs is installed a second lamp, suitably shaded, which can be turned on and off at will for the reading of the graduated circle on the back of the set of discs nearest the observer. (Since the above paper was presented this newer type of apparatus has been taken overseas for the purpose of studying and checking up the diurnal variations in the ocular condition of the aviators on the western front.)

With both types of apparatus, all readings are made in terms of degrees of open sector. These readings can after any number of sets of observations be converted into units of time by a simple process of calibration. Smoked paper is clipped to the disc across the open sector; the pendulum is released with the weights, the starting point, etc. just as they were in the original determinations; and a time line is run across the open sector by means of an electric tuning fork whose vibration frequency is known. The paper can be removed, shellacked and counted at leisure. In counting, the given degree values can be laid off on the shellacked record by means of another protractor. If the discs are made of material so light that the different positions of the moveable discs do not change by significant amounts the relative accelerations of the pendulum at the different points in its path,[9] a calibrating chart may be made once for all for the full range or any range of open sector that may be desired. Another method which we have used is to have contacts soldered to the edges of the sector, in circuit with an electro-magnetic marker writing on the smoked paper of a kymograph. Because of a certain amount of lag in this system of recording, the method was abandoned in favor of the one described. In practical use, however, where an exact quantitative rating of performance is not required, there is no particular need of converting the readings on the scale into units of time. This is especially true if the apparatus is used, as is the Snellen method of rating acuities, merely to classify performance roughly by the rank method. That is, in this case it is set to give in turn the different levels of performance chosen, and the eye is rated by the highest level which it is able to attain.

[9] Light cardboard, for example, could be used, if desired, for these discs instead of aluminum.

TABLE

SHOWING THE INERTIA OF ADJUSTMENT OF THE
Observers with nor

Observer	Age	Degree values: Near object	Degree values: Near to far	Degree values: Near to far and back to near	Time values (sec.): Near object	Time values (sec.): Near to far	Time values (sec.): Near to far and back to near	Individual Deviation, Near to far: Seconds	Individual Deviation, Near to far: Per cent
Sl.........	25	1	31	64	0.02	0.50	0.96		
Fl.........	26	1	42	73	0.02	0.68	1.05	0.18	36.0
St.........	23	1	38	85	0.02	0.64	1.17	0.14	28.0
C..........	25	1	44	103	0.02	0.72	1.37	0.22	44.0
Mc........	27	1	53	105	0.02	0.77	1.41	0.27	54.0
Ln.........	26	1	39	105	0.02	0.65	1.41	0.15	30.0
F..........	40	2	54	124	0.04	0.775	1.85*	0.275	55.0

* Compare this result with that obtained with the same observer with Apparatus II. It will be the first apparatus than with the second in all cases in which the determinations were made on the to cut it off just as soon as it was discriminated.

I

Eye for Clear Seeing at Different Distances
mal eyes. Apparatus I

differences from quickest					
Near to far and back to near			Supplementary data		
Seconds	Per cent	Acuity	Near point (cm.)	Refraction	Muscles
		O.D.:6/4	11.5	Emmetropic	1 Exo.
		O.S.:6/4	12.5	+.12 cyl. ax. 90°.	
0.09	9.4	O.D.:6/4	12.5	+.50 S.+.25 cyl. ax. 180°.	2 2/3 Eso, 1/3 LH
		O.S.:6/4	12.5	+.62 S.	
0.21	21.9	O.D.:6/4	10.4	+.25 S. + .25 cyl. ax. 75°	2 1/2 Eso, 1 R H
		O.S.:6/4	10.4	+.25 S. + .12 cyl. ax. 90°	
0.41	42.7	O.D.:6/4	11.3	—.25 cyl. ax. 80°	2 Exo, 1 RH
		O.S.:6/4	11.3	—.12 cyl. ax. 95°	
0.45	46.9	O.D.:6/4	12.5	Emmetropic	1 Eso
		O.S.:6/4	12.5	Emmetropic	
0.45	46.9	O.D.:6/4	11.5	+.25 S.	1 1/4 Eso, 1 RH
		O.S.:6/5	10.5	—.25 S.	
0.89	92.7	O.D.:6/4	15.0	+.12 cyl ax. 120°.	3 Eso
		O.S.:6/4	15.0	+.12 cyl. ax. 15°	

remembered that we have stated (p. 46), that a longer time was required for the double excursion with same observer, owing to the tendency of the eye to linger on the far object when no provision was made

TABLE

SHOWING THE INERTIA OF ADJUSTMENT OF THE
Observers with nor

Observer	Age	Degree values* Near object	Degree values* Near to far	Degree values* Far to near	Degree values* Near to far and back to near	Time values (seconds) Near object	Time values (seconds) Near to far	Time values (seconds) Far to near	Time values (seconds) Near to far and back to near	Individual diff Near to far Seconds	Individual diff Near to far Percent
H............	19	1	48	44	92	0.02	0.63	0.39	1.02		
Lz............	25	1	56	48	104	0.02	0.75	0.42	1.17	0.12	19.0
Bk............	25	1	59	55	114	0.02	0.77	0.47	1.24	0.14	22.2
L............	19	2	59	64	123	0.04	0.76	0.565	1.325	0.13	20.6
Rg............	28	1	55	70	125	0.02	0.715	0.61	1.325	0.085	13.5
Ty............	24	1	55	87	142	0.02	0.69	0.76	1.45	0.06	9.5
D............	22	1	51	63	114*	0.02	0.825	0.675	1.50	0.195	31.0
S............	24	2	68	75	143	0.045	0.85	0.66	1.51	0.22	34.9
F............	40	1	64	81	145	0.02	0.79	0.73	1.52	0.16	25.4
B............	19	1	57	92	149	0.02	0.705	0.82	1.525	0.075	11.9
M............	18	1	79	70	149	0.02	0.94	0.635	1.575	0.31	49.2
Rs............	24	2	98	60	158*	0.06	1.16	0.60	1.76	0.53	84.1
With glasses,—Apparatus II.											
W............	25	3	77	42	119*	0.09	1.02	0.46	1.48	0.39	61.9
Bt............	27	2	63	75	138*	0.04	0.89	0.68	1.57	0.26	41.3
R............	31	1	105	43	148	0.02	1.17	0.405	1.575	0.54	85.7
Hk............	27	1	82	62	144	0.02	1.015	0.565	1.58	0.385	61.1

* In the four cases marked with an asterisk, longer exposures were needed than could be gotten
exposure needed was secured by changing the positions of the weights on the bar.

II

EYE FOR CLEAR SEEING AT DIFFERENT DISTANCES
mal eyes,—Apparatus II

erences: Deviation from quickest				Supplementary data			
Far to near Seconds	Percent	Near to far and back to near Seconds	Percent	Acuity	Near point (cm.)	Refraction	Muscles
				O.D.:6/4	10.3	Emmetropic	1 1/2Eso.
				O.S.:6/4	10.3	Emmetropic	Add:Abd+20:9
0.03	7.7	0.15	14.7	O.D.:5/4	12.5	—.12 cyl. ax. 180°	3 Eso, 1 RH
				O.S.:6/4	13.0	Emmetropic	Add: Abd=26:5
0.08	20.5	0.22	21.6	O.D.:6/4	13.0	+.12 cyl. ax. 60°	1/3 RH
				O.S.:6/4	12.5	+.12 cyl. ax. 120°	Add: Abd=22:11
0.175	44.9	0.305	29.9	O.D.:6/4	11.0	Emmetropic	1 Exo
				O.S.:6/4	8.6	—.25 cyl. ax. 5°	Add: Abd=10:8
0.22	56.4	0.305	29.9	O.D.:6/4—	12.0	—.12 cyl. ax. 122 1/2°	1 1/4 Eso
				O.S.:6/4 —	13.0	Emmetropic	
0.37	94.9	0.43	42.2	O.D.:6/4	12.0	Emmetropic	1 Exo
				O.S.:6/4	10.5	Emmetropic	Add: Abd=22:7
0.285	73.1	0.48	47.1	O.D.:6/4	9.5	—.12 cyl. ax. 157 1/2°	3/4 Eso
				O.S.:6/4	9.5	—.25 cyl. ax. 17°	Add: Abd=18:5
0.27	69.2	0.49	48.0	O.D.:6/5+	10.5	—.25 S.	1 Eso
				O.S.:6/4	11.0	Emmetropic	Add: Abd=14:8
0.34	87.2	0.50	49.0	O.D.:6/4	15.0	—.12 cyl. ax. 120°	3 Eso
				O.S.:6/4	15.0	—.12 cyl. ax. 15°	Add:Abd=12:3 3/4
0.43	110.3	0.505	49.5	O.D.:6/4	9.0	—.25 cyl. ax. 150°	1 Eso, 1 1/8 RH
				O.S.:6/4	11.0	—.25 cyl. ax. 5°	Add: Abd=20:10
0.245	62.8	0.555	54.4	O.D.:6/4	8.0	Emmetropic	1 Exo
				O.S.:6/4	8.0	Emmetropic	
0.21	53.8	0.74	72.5	O.D :6/4	9.0	Emmetropic	4 LH
				O.S.:6/4	10.5	—.25 cyl. ax. 90°	Add: Abd=14:9
				With glasses,—Apparatus II			
0.07	17.9	0.46	45.1	O.D.:6/6	12.0	+.25 cyl. ax. 180°	1 1/2 Eso
				O.S.:6/15	12.5	+.50 cyl. ax. 115°	Add: Abd=20:9
0.29	74.4	0.55	53.9	O.D.:6/5+	9.5	—3 S.—1.37 cyl. ax. 15°	Ortho
				O.S.:6/5+	10.5	—3 S.—1.37 cyl. ax. 165°	Add: Abd=20:9
0.015	3.8	0.555	54.4	O.D.:6/4	9.0	—1 S.—.37 cyl. ax. 150°	1/4 Exo, 1/2 RH
				O.S.:6/4	10.0	—.25 S.—.25 cyl. ax. 180°	Add: Abd=24:8
0.175	44.9	0.56	54.9	O.D.:6/4—	11.0	—.50 S.—.25 cyl. ax. 120°	3/4 Eso, 1/2 RH
				O.S.:6/5+	10.5	—.87 S.—.37 cyl. ax. 60°	Add: Abd=21:9

by changing the setting of the discs with a given position of the weights on the bar. The range of

TABLE III

Showing a comparison of the time required to discriminate the far object in the most favorable meridian and the meridian 90 degrees from this in cases of low astigmatism,—also the difference in the time required for the most favorable meridian and for meridians 5 degrees on either side

Observer	Refraction	Time of discrimination of far object in seconds: Most favorable meridian	Time of discrimination of far object in seconds: At 90° from most favorable meridian	Difference for two meridians: Seconds	Difference for two meridians: Per cent	Difference produced by a change of 5° in either direction: Seconds	Difference produced by a change of 5° in either direction: Per cent
R(O.S.)...	—.25 cyl. ax. 5°	0.70	0.95	0.25	35.71	0.09	12.86
R(O.D)...	—.37 cyl. ax. 150°	0.96	1.40	0.44	45.83		
F.........	+.12 cyl. ax. 120°	0.80	1.12	0.32	40.00	0.14	17.50
B.........	—.25 cyl. ax. 150°	0.65	1.02	0.37	56.92	0.06	9.23
T.........	—1.25 cyl. ax. 170°	0.55	0.84	0.29	52.73	0.12	21.82
L.........	—.25 cyl. ax. 5°	0.76	0.88	0.12	15.79		

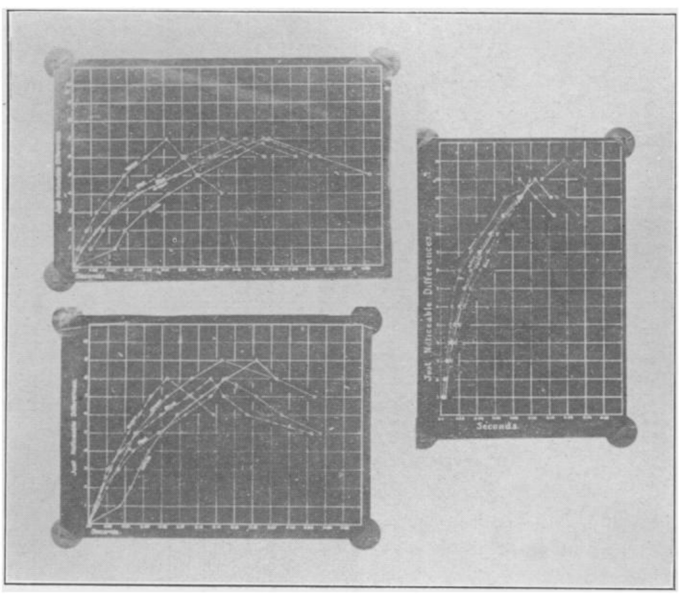

FIG. I

Showing the results of a determination of the lag in visual sensation in its relation to wave-length and intensity of light. In A (upper left) the lights employed were made photometrically equal to 0.057 meter-candles; in B (lower left), at 0.151 meter-candles; and in C (right), at 1.21 meter-candles.

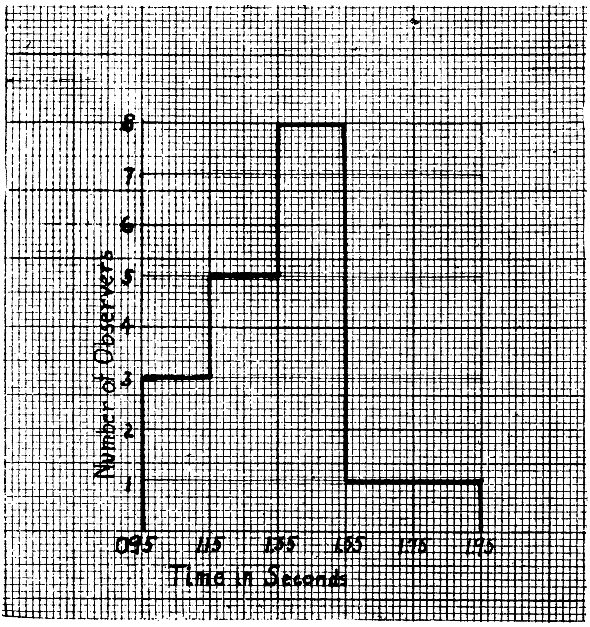

FIG. II

Representing the relative distribution of 18 observers graded with reference to speed of adjustment for clear seeing at different distances.

Once a feasible method and apparatus are had for determining the speed and accuracy with which the eye may be adjusted for clear seeing at different distances a number of problems are open for investigation. As already indicated two of the points which we hope to study in the near future are diurnal variations and the slowing effect of age. The latter of these points becomes of importance if men of the age of the late Mayor Mitchell are to enter aviation and other vocations for which speed and accuracy of ocular adjustments are a prerequisite. The results which we have obtained thus far on older subjects (not included in the preceding tables) suggest that above the age of 30, the eye becomes not only slower in its reactions but increasingly liable to lapses and depressions lasting through longer or shorter intervals of time which make it a tardy and unreliable instrument for much of the work it is called upon to do, more particularly for the special vocations requiring speed of performance. That such lapses are a menace to the

aviator is now pretty generally recognized. It is a matter of common report that even the young aviator under the strain of the prolonged performance of his task grows stale. If so, it is obvious that a careful check should be kept on the sensory and motor foundations of his fitness for his work. In this procedure the speed of reaction of his skeletal as well as his ocular muscles doubtless should be included (cf. foot-note p. 44). By adding these supplementary reactions to the test a broader basis would be laid for keeping track of the variations in the aviator's ability to see his objects quickly and to perform the reactions needed for the control of his machine. In calling attention to these subsidiary questions, however, we do not wish to obscure what we believe to be the most promising application of the test, namely the initial grading of men as to fitness for work requiring special ocular capacities.

The apparatus described is now being used in France for the study of the diurnal variations in the aviator's ocular fitness for his work. It is also being used by the Ophthalmological Division at the Medical Research Laboratory at Mineola. Among the problems in prospect there the following three may

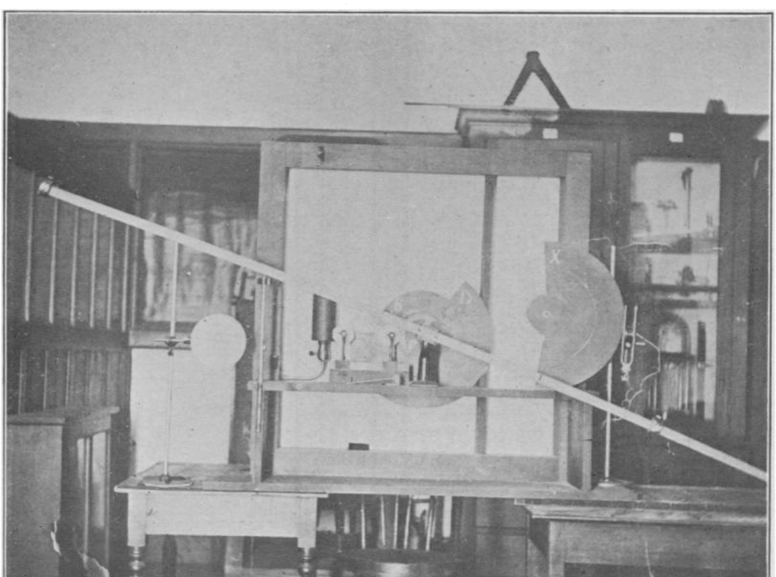

FIG. III

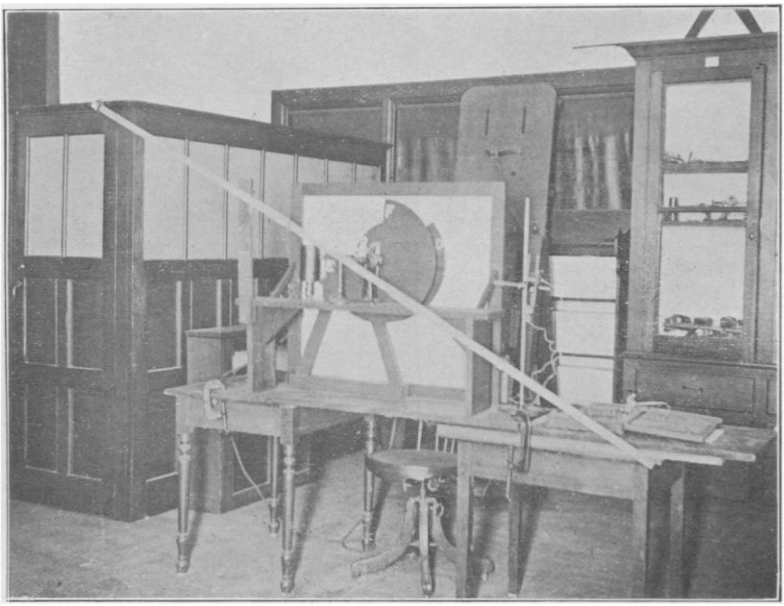

Fig. IV

be noted: (1) the standardization of the test for the selection of aviators, (2) a study of the diurnal variations in the aviator's ocular fitness for his work, and (3) a study of the ocular effects of oxygen poverty.